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An update on dimensions of consciousness

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ABSTRACT
Evidence is presented to support the hypothesis that "binding" of the senses to produce a combined sensory experience is made possible by the allocation of each sense to its own dimension.

KEYWORDS Attractor; binding; consciousness; dimensions; electroencephalogram; nonlinear dynamics

THE PROBLEM OF PERCEPTUAL SPACE

A mother takes George, her 6-year-old child, to the zoo. An elephant stands 20 feet away separated by a low wall and a moat. George looks at the elephant. Light from the elephant is focused on George's retina and digitized into a staccato stream of nerve impulses, which then race along the million fibers in each optic nerve. Note that the elephant did not enter George's brain; coded impulses did. The visual signals are processed, and the next thing George knows the elephant appears in his visual perceptual space. George is the percipient, but what and where is the percept, that is, the elephant? Milliseconds before the percept appeared, all of the information describing the elephant consisted of nerve signals; the brain did not construct a flesh-and-blood pachyderm. George's neurons exist in physical space but the percept itself is not a physical object in physical space; it is a nonphysical construct in nonphysical space. The percept is also scale free; it has no size. A 5-ton elephant will not fit into the head of a 50-pound child.

The real, physical elephant is 20 feet away from George, and the visual image that George enjoys seems to correspond with that estimated distance. However, we know that the neural machinery producing the percept is in the brain—so is the percept inside or outside George's brain? The answer is neither, and therein lies the problem.

To assign a location in physical space, either inside or outside the skull, to a nonphysical object in nonphysical space is a nonsequitur. As Bertrand Russell pointed out 90 years ago, "Physical and perceptual space have relations, but they are not identical, and failure to grasp the difference between them is a potent source of confusion."[1] An enormous amount of time and effort has been spent in the search for the fabled anatomical correlate of consciousness. The percept is in fact a veridical illusion. Like a rainbow, it is real but intangible.

The problem with consciousness is to explain the subjective with objective empirical measurements.

DIMENSIONS OF CONSCIOUSNESS IN PERCEPTUAL SPACE

Before we embark upon a possible explanation of consciousness, a small amount of background knowledge is required.

Figure 1 displays the Koch curve. Triangles are added to triangles to create the "wiggly" line at the bottom where the original shape is repeated in smaller and smaller versions of the original. The line is more than one dimension but less than two. It is a fraction of a dimension, 1.26 (log4/log3). That is why the shape is called a *fractal*. There are many fractal shapes in the human body, such as the lungs, the arterial tree, and the venous and nervous systems.

Another element is the attractor. In *Figure 2*, the circle is the attractor and contains more information than observation of the pendulum itself.[2] If you grab the pendulum and stop it swinging, all you can deduce is its position at the time of rest; by examining the attractor plot, the pendulum's position and velocity may be observed. If the pendulum wobbles, the circle becomes lumpy, but it is *attracted* back into its circular shape—hence the name. Attractors are associated with the electroencephalogram (EEG) and, as with the Koch curve, their dimensions are noninteger.

Figure 3 illustrates pendulum dynamics, showing the one-dimensional circular pendulum attractor stretched out in time

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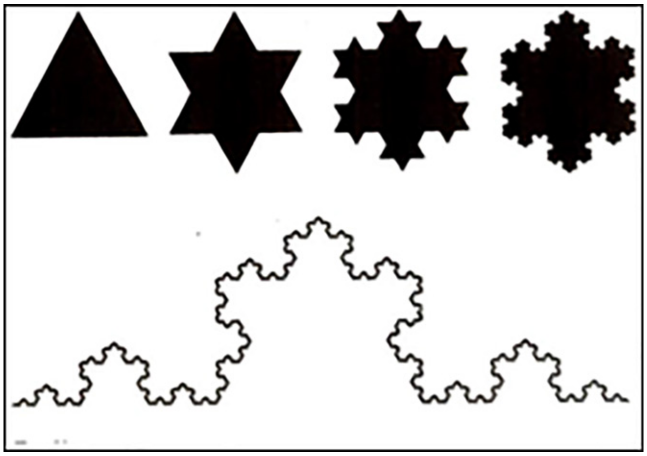

Figure 1. The Koch curve at 1.26 dimensions, an example of a fractal.

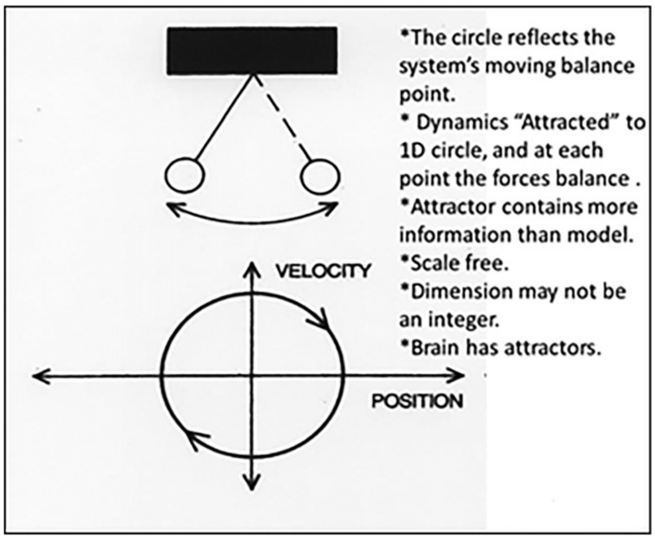

Figure 2. A one-dimensional attractor in phase space, considering the dynamics of a simple pendulum expressed by plotting velocity versus position. Adapted from Crutchfield et al.[2]

Figure 3. Pendulum dynamics. As gravity gives weight to physical objects, attractors give direction to dynamic systems. They are both invisible. If a brain is cut open, there are only neurons to be seen, but no attractors. An attractor has a dimension, which is one measure of its complexity.

and viewed from the side. The resulting sine wave is beginning to resemble a scalp recording of brainwaves or the EEG. Computer programs exist whereby the recorded EEG may be converted to display its own attractor in real time *(Figure 4)*.

Thinking in higher dimensions

Now that fractals and attractors have been addressed, we must grapple with the idea of understanding previously unsolvable problems by thinking in higher dimensions.

In 1610, Galileo Galilei (1564–1642) reported three "fixed stars" close to Jupiter in *Siderius Nuncius* and correctly deduced that they were not fixed but were moons orbiting the planet. It took this kind of mental leap to imagine the moons traveling in their own orbits, thereby adding a dimension to the existing cosmic model. This refuted Aristotelian cosmology, which placed the Earth at the center of the universe, and further supported the heliocentric view of the solar system.

Three hundred years later, Albert Einstein (1879–1955) indulged in thought experiments (*Gedankenexperiment*). One of the results was to add a dimension to expand our concept of the cosmos. He demonstrated that in addition to the three dimensions of physical space, time could be added as a fourth dimension on an equal footing with the others. Recent theories in particle physics postulate 10 dimensions for superstring theory and 11 dimensions to explain M-theory.

Sometimes Darwinian forces took a hand in manipulating our perception of dimensions. Our separated eyes have permitted the evolution of stereoscopic sight, which increases our vision from two to three dimensions, thereby allowing us to enjoy depth perception. It should come as no surprise, therefore, when contemplating the intractable mystery of consciousness, that the consideration of dimensions should also play an important part.

Examination of consciousness as sensory dimensions

Recourse to nonlinear dynamics was used to investigate—and for the first time to demonstrate—the dynamic stages of emergence from general anesthesia, and at this time we described our methods.[3] The progression from point to periodic to torus attractor before return of consciousness helped confirm that in normal consciousness the brain dynamics are chaotic. The progression of attractors mentioned previously is invariably followed by chaotic activity as brain activity returns. However, the demonstration of chaotic behavior in a conscious human brain did not solve the two most intractable problems associated with consciousness research.

In "Dimensions of Consciousness,"[4] two difficult problems topped the list of items that required explanation. First was the "phenomenal problem": the redness of a rose is a subjective experience or quale, which exists in our perceptual space and which is derived from a physical observation. Like observing a rainbow, the percept of the rose is a veridical illusion, real but intangible. There is no way that one person can describe to another what it is like to see red. The second difficulty is to explain "the binding problem." Though our sensory centers are scattered around the brain, we manage to enjoy conscious moments when senses are combined without interfering with one another. Consciousness investigators call

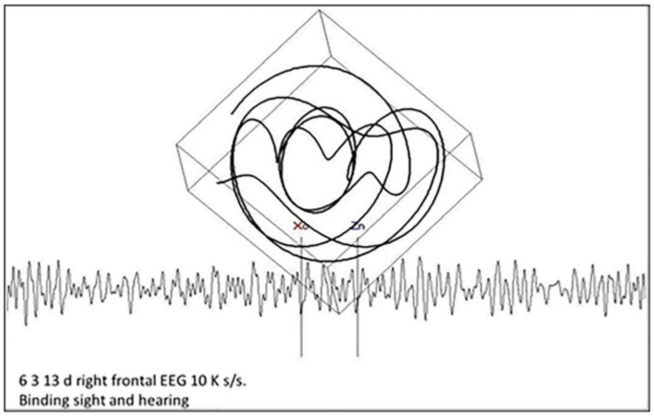

Figure 4. A frontal electroencephalogram (EEG) with its associated attractor above it. The EEG is a lower-dimensional derivative of the attractor itself. The attractor is reconstructed by delay coordinate embedding and may be viewed in real time as a rotating movie (see https://www.youtube.com/watch?v=z6V0sQq6EBA). The movie clip is a frontal EEG with the attractor recorded at 1/1000 natural speed during mental arithmetic (subtracting 17's sequentially from 500). Note that during intense concentration, without the senses intruding into perceptual space, the attractor is generally flattened, that is, of a low dimension.

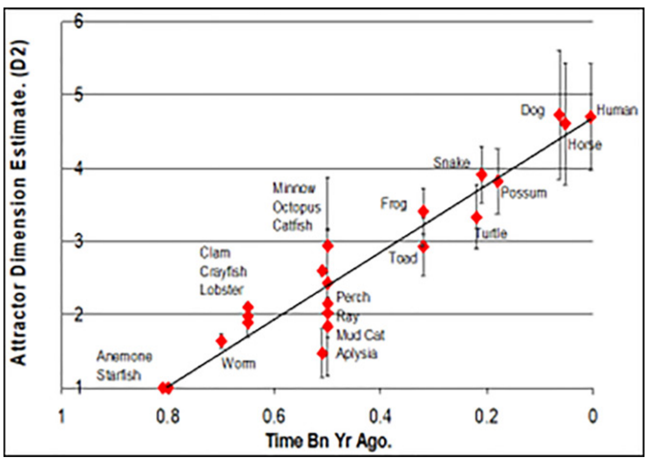

Figure 5. The highest recorded attractor dimension (dimension 2) plotted against the approximate time of each species' first appearance (billions of years ago).

this combined sensory experience a *gestalt*, and here some progress has been made.

We studied the evolution of consciousness by plotting attractor dimensions of 21 species against the age of their oldest fossils. For example, fossil frog brains are virtually the same as the brains of today's frogs. The frog of today is a surrogate for its long-dead ancestor. We measured the frog's EEG attractor dimension and plotted this at about 320 million years ago, the age of the first frog fossil. Permission to measure the EEG of wild animals was obtained from the local agricultural extension agent on condition that the animals were returned unharmed to the wild after recordings were made. We showed that the greatest attractor dimensions for each species increased steadily during the period of animal evolution *(Figure 5)*. This increase reflected the greater

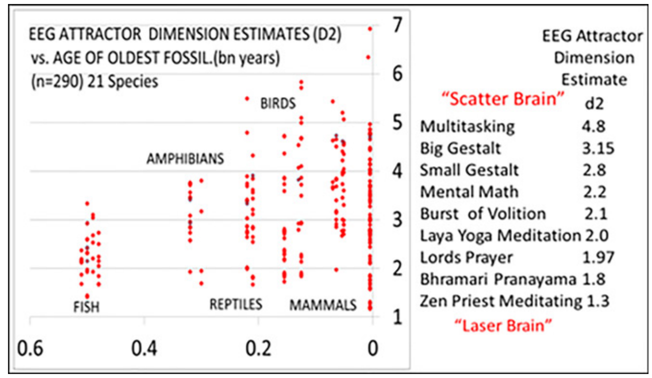

Figure 6. Electroencephalogram attractor dimension against the age of the oldest fossil. These are combined results from 290 recordings from 21 different species. Humans are on the far right. The table on the right shows examples of the variety of attractor dimensions associated with different conscious endeavors—from "laser brain" to "scatter brain."

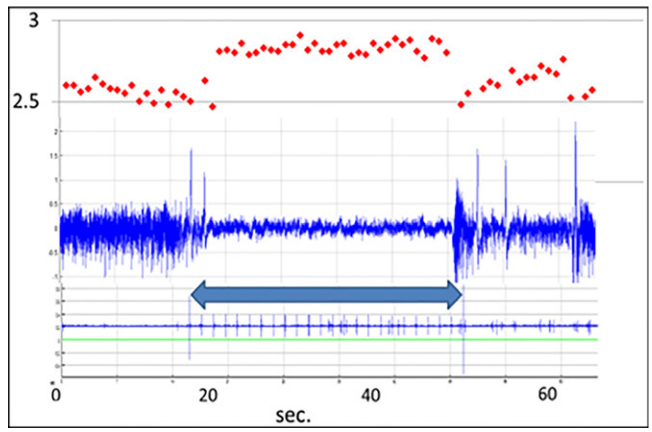

Figure 7. Frontal electroencephalogram showing the effect of a clicking/flashing metronome for the duration of the thick arrow. The attractor dimensional estimate (d2) is shown as diamond-shaped dots.

dynamical complexity and relative size of the vertebrate brain and came as no surprise.

When we looked at *all* of the results in *Figure 6*, not just the highest attractor dimensions, we were puzzled. It was obvious that by concentrating on the highest attractor dimensions we had overlooked the variety of dimensions that the brain employs in everyday consciousness. This variety probably holds the secret to binding. How can we process different senses simultaneously, especially when the sites for sensory processing are scattered in different parts of the brain?

In *Figure 6*, human studies are at the right-hand side of the graph. Why does each animal reside in its own cluster? Why do the clusters increase in size as the vertebrate brain evolves? How may a catfish sometimes have a larger attractor dimension than a professor? The answer lies in the number of senses being employed at the time of measurement.

The animal's chance of survival is improved if it can see, smell, and listen all at the same time. How does the brain do this without mixing up the signals? How does an animal cope with attractor dimensions over three dimensions? By looking back to see what the humans were thinking at the

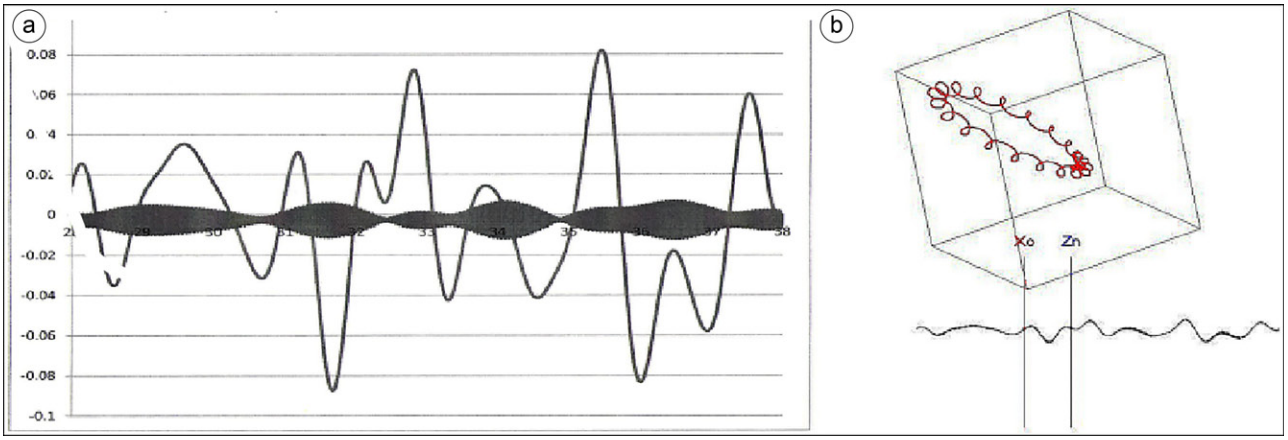

Figure 8. **(a)** Two carrier frequencies of about 1 Hz and 20 Hz extracted from the recording in *Figure 7* while the metronome was clicking/flashing. How may hearing and vision, for example, be perceived simultaneously and yet retain their separate qualities? **(b)** The same two frequencies isolated from the small gestalt electroencephalogram and recombined in three dimensions by delay coordinate embedding. Remember that the electroencephalogram is a degraded version of the corresponding attractor. When the attractor is reconstructed, the high-frequency signal is embedded within the slower-frequency signal. The lazy circle represents the low frequency and the high-frequency signal is the tight coil embedded within it at right angles.

time of the EEG recording, I believe that we may have found an answer. We constructed a league table of human attractor dimensions, from laser brain to scatter brain, from one to approximately five dimensions *(Figure 6)*.

The smallest four attractors (1.3–2.0 dimensions) all involved subjects meditating or at prayer. Under these conditions, the conscious mind is closed to the senses while the subject concentrates on the prayer or meditates. Ideally the subject sits comfortably with a minimum of sensory input. With the EEG burst of volition when the subject decides to hit a button, and with mental arithmetic, the subject is concentrating hard on a single task (attractor dimensions 2.0 and 2.1). During the small gestalt, the subject is suddenly exposed to a clicking and flashing metronome, which then occupies his perceptual space *(Figure 7)*.

During the big gestalt (*gestalt* in this instance means a combined sensory experience), the subject tastes citric acid (lemon juice), listens to the weather on the radio, sniffs acetone, and reads Plato's *Republic*. The dimensions increase accordingly until the subject is asked to multitask, when the attractor dimension increases to 4.8. It was beginning to appear that with every extra sense employed in perceptual space, another dimension is required. Why is that?

Each signal inhabits its *own dimension (Figure 8)*. The usual way to move from one dimension to another is to depart at right angles—for example, from a line to a square and then a square to a cube. In this way, the signals are separate but bound together at the same time. In other words, sensory binding has been accomplished while the perception of vision and hearing have been kept separate.

The hypothesis outlined above fits well with Freeman's mass action.[5] In Freeman's mass action, an odor, for example, stimulates the whole olfactory cortex, which generates a gamma burst in an amplitude modulation spatial pattern. This spreads to the whole sensory cortex in two-dimensional arrays, like wind blowing over a wheat field (Maxwellian vector field; see Glossary) to be deposited like layers in a three-dimensional printer to construct a cinematographic image in perceptual space. The layers are deposited at about 40 Hz and the higher-dimensional, apparently seamless percept may represent a content of more than three dimensions. Thus, by employing nonphysical perceptual space, the percipient is freed from the constraint imposed by the event horizon of three-dimensional physical space.

A significant group of consciousness investigators believe that consciousness arises from quantum effects,[6,7] whereas others think that consciousness itself is fundamental in the universe. Consciousness is so mysterious that we all may be right.

GLOSSARY

Attractor. A point in multidimensional phase space that is used to describe a system toward which a system tends to evolve regardless of the starting conditions.

Billion. In American English, one thousand million. Until 1976, a billion in British English was a million million, at which time the American English usage was adopted.

Carrier frequencies. Amplitude-modulated brain impulses that carry information from the sensory cortex to the frontal areas and into perceptual space.

Chaos. Behavior so unpredictable as to appear random, due to great sensitivity to small changes in initial conditions.

Consciousness. A state of being awake and aware of one's surroundings.

Delay coordinate embedding. The plotting of a digital signal that is repeated three times with an appropriate delay in three dimensions to give an approximation of the associated attractor:

1, 2, 3, 4, 5, 6, 7, 8, 9
    1, 2, 3, 4, 5, 6, 7, 8, 9
        1, 2, 3, 4, 5, 6, 7, 8, 9. Plot 3, 2, 1. Then 4, 3, 2. Then 5, 4, 3, and so on.

Electroencephalogram. Recording of voltage changes at the scalp from underlying brain tissue. Measured in thousandths of a volt.

Gestalt. Literally form or pattern. The brain creates perception that is more than simply the sum of sensory inputs. A combined sensory experience.

Hertz (Hz). The SI unit of frequency equal to one cycle per second.

Intangible. Unable to be touched or grasped; not having a physical presence.

Vector field. As an example, a map of Texas depicting both wind speed *and* direction (a Maxwellian vector field), in contrast to a map of Texas showing temperatures at different points all over the state, which is a Newtonian scalar field.

Veridical; *genuine.* Something that is intangible and real at the same time. An example is a rainbow as a veridical illusion. This apparent contradiction is typical of the problem of explaining consciousness.

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